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## ENCAPSULATION FOR A THREE-DIMENSIONAL MICROSYSTEM

### FIELD OF THE INVENTION

- 5 The present invention relates to an encapsulation of a three-dimensional microsystem wherein the encapsulation comprises one or more layers with essentially constant thickness.

### BACKGROUND OF THE INVENTION

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Protective encapsulation is the final step in microsystem manufacturing. In most cases the encapsulation make up the main part of the microsystem volume and most of the price. This is the background for the interest in reducing the amount of encapsulation material used. To achieve a significant reduction in the amount of materials used, the right choice of materials and processing methods is crucial for the lifetime, performance, and cost of the system.

Lifetime and performance are strongly connected with the fact that many systems are exposed to chemically, physically and electro-magnetically hostile environments. Microelectronics is e.g. very sensitive to corrosion due to water encapsulated on the device or water penetrating the encapsulating material. Therefore, a lot of effort is put into avoiding the encapsulation of water and using protective tight materials and seals/and/or bondings between silicon, metals, polymers, and ceramics.

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Packaging concepts for silicon based micro mechanical sensors exposed to harsh environments are disclosed in "Reliability of industrial packaging for microsystems" by de Reus et al., Microelectronics Reliability 38 (1998) 1251-1260. Two-dimensional protective properties of coatings of silicon carbide, Si-Ta-N, Parylene C, and diamond-like carbon are described and, further, different glue types for sensor chip mounting have been investigated for leakage, degradation, and influence on sensor performance.

30

A lot of related work has been going on during the last 25 years, but the focus of this work has not been on three-dimensional Chip Scale Packaging (CSP), but on how to protect two-dimensional components and conductors on Printed Circuit Boards (PCBs) and later microsystems with coatings.

5

A bi-layer protective coating system for Micro Electro Mechanical Systems (MEMS) is described in "Interface-Adhesion-Enhanced Bi-layer Conformal Coating for Avionics Application" by Wu et al., 1999 International Symposium on Advanced Packaging Materials p. 302-310. The bi-layer structure is selected because of

10 property limitations of a single material. The first layer is mainly applied to planarize the MEMS surface. A second functionality of the first layer is to form a durable dielectric insulation, stress relief, and shock/vibration absorber. The second layer forms a barrier.

15 In "C-SHIELD Parylene allows major weight saving for EM shielding of microelectronics" by Noordegraaf et al., PEP'97, The first IEEE International Symposium on Polymeric Electronics Packaging, 189-196, a two-dimensional conformal bi-layer coating system for microelectronics protection is described. The first layer serves primarily as an electrical insulation / chemical barrier whereas the

20 top layer serves as Electro-Magnetic Interference (EMI) protection.

Finish Patent application FI 956226 describes a method for coating electronics conformally with polyaniline for EMI shielding of electronics, with emphasis on PCB's.

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US 5,639,989 discloses two-dimensional multilayer conformal EMI coatings for PCB protection. The first layer is an insulating layer whereas the others are shielding layers tuned to a specific shielding application.

30 US 4,977,297 and US 4,982,056 disclose an electronic circuitry having on at least one of its exposed surfaces a protective coating of Teflon® AF 1600.

## SUMMARY OF THE INVENTION

It is an object of the present invention to provide a three-dimensional Chip Scale Packaging (CSP) that minimises the overall volume of an encapsulated  
5 microsystem.

It is a further object of the present invention to provide an encapsulation protecting the microsystem against environmental influences such as chemical attack, physical attack, fluid penetration, electromagnetic interference (EMI), etc.,  
10 separately or in various combinations.

It is still a further object of the present invention to provide an encapsulation that protects the environment against the microsystem such as against leakage of chemicals from the microsystem to the environment.

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The above-mentioned and other objects are complied with by providing in a first aspect an encapsulation for a three-dimensional microsystem having an outer surface, said encapsulation covering at least a part of the outer surface of the microsystem, the encapsulation comprising

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- a first layer of a first material, said first layer defining a first interface region with the outer surface of the three-dimensional microsystem,
- a second layer of a second material having an outer surface, said second layer  
25 being held by the first layer and defining a second interface region with said first layer,

wherein the shortest distance between the first and second interface regions is essentially constant, and wherein the shortest distance between the first interface  
30 region and the outer surface of the second layer is essentially constant and between 5  $\mu\text{m}$  and 500  $\mu\text{m}$ .

In the present context, the shortest distance is measured in a direction substantially perpendicular to the outer surface of the outermost layer. The shortest distance between the first interface region and the outer surface of the second layer should, thus, be understood as the distance between the first  
5 interface region and the outer surface of the second layer in a direction substantially perpendicular to the outer surface of the microsystem.

The encapsulation may further comprise a third layer of a third material being held by the second layer and defining a third interface region with said second layer,  
10 the shortest distance between the first interface region and the outer surface of the third layer, thus, being determined as the distance between the first interface region and the outer surface of the third layer in a direction being substantially perpendicular to the outer surface of the third layer.

15 In a preferred embodiment the shortest distance between the first interface region and the second interface region may be between 5  $\mu\text{m}$  and 250  $\mu\text{m}$ , such as between 10  $\mu\text{m}$  and 250  $\mu\text{m}$ , such as less than 250  $\mu\text{m}$ , such as less than 200  $\mu\text{m}$ , such as less than 150  $\mu\text{m}$ , such as less than 100  $\mu\text{m}$ , such as less than 75  $\mu\text{m}$ , such as less than 50  $\mu\text{m}$ , or even such as less than 20  $\mu\text{m}$ , such as less than 15  
20  $\mu\text{m}$ , or such as less than 10  $\mu\text{m}$ , such as approximately 5  $\mu\text{m}$ .

The shortest distance between the first interface region and the outer surface of the second layer may be essentially constant and between 5  $\mu\text{m}$  and 500  $\mu\text{m}$ , such as between 10  $\mu\text{m}$  and 500  $\mu\text{m}$ , such as less than 500  $\mu\text{m}$ , such as less than  
25 400  $\mu\text{m}$ , such as less than 300  $\mu\text{m}$ , preferably less than 250  $\mu\text{m}$ , such as less than 200  $\mu\text{m}$ , such as less than 125  $\mu\text{m}$ , such as less than 100  $\mu\text{m}$ , such as less than 50  $\mu\text{m}$ , or even such as less than 20  $\mu\text{m}$ , such as less than 15  $\mu\text{m}$ , or such as approximately 10  $\mu\text{m}$ .

30 In the present context the term microsystem should be understood as a micromechanical transducer, sensor or multi-chip system. The microsystem may be a pure mechanical system or it may be a combination of a mechanical and an

electrical system e.g. an accelerometer. Such systems may be adapted for measuring the flow of a fluid, static or dynamic air pressure, temperature, acceleration, velocity, etc.

- 5 The three-dimensional microsystem may be a miniature component, which has at least one transducer function that converts electric or optical energy to or from energy in another domain, such as a mechanical, magnetic, chemical, and/or biological domain, or the at least one transducer function may convert energy between electric and optical energy and/or vice versa. The transducer functions  
10 may be used for sensing, actuation or energy converting purposes. Several transducer functions may be combined in one system, and also signal-conditioning functions may form part of the system.

Typically, three-dimensional microsystems are micromechanical sensors like  
15 pressure and flow sensors, accelerometers, or chemical or biochemical sensors or sensor systems. A three-dimensional microsystem may further be electro-optical components and integrated optical systems, which contains several optical functions. Other examples are actuators such as miniaturised valves, pumps and/or relays. In more complex three-dimensional microsystems such as MEMS  
20 (micro electromechanical systems), micro-fluidic systems or chemical/biochemical microsystems, several actuator and/or sensing functions may be combined to a miniature system often integrated with electric or optic signal conditioning functions.

- 25 In a second aspect, the present invention relates to an encapsulation for a three-dimensional microsystem having an outer surface, said encapsulation covering at least a part of the outer surface of the microsystem, and the encapsulation comprises
- 30 - a layer comprising a plurality of materials, said layer defining a first interface region with the outer surface of the three-dimensional microsystem and having an outer surface, wherein the material composition of the layer, in a region between the first interface region and the outer surface of the layer and along a direction

defined as the shortest distance between the first interface region and the outer surface, varies as a function of a distance from the first interface region.

Hereby, one layer of material may be adapted to shield the microsystem  
5 effectively against different environmental effects so that different parts of the one layer of material shield against different environmental effects according to the composition of the layer.

The plurality of materials may for example comprise a polymer, and the polymer  
10 may comprise a filler. The filler may comprise a material selected from the group consisting of ceramics and metals. A ceramic filler may reduce the thermal coefficient of expansion (TCE) of the material so as to for example approach the low TCE of silicon, and further enhance the thermal conductivity of the material. A metallic filler may for example enhance the conductivity of the material.

15 Preferably, the shortest distance between the first interface region and the outer surface may be essentially constant and the shortest distance may be between 5  $\mu\text{m}$  and 500  $\mu\text{m}$ , the shortest distance may thus be larger than 5  $\mu\text{m}$ , such as larger than 10  $\mu\text{m}$ , or even larger than 15  $\mu\text{m}$ , such as larger than 20  $\mu\text{m}$ , and the  
20 shortest distance may at the same time be less than 500  $\mu\text{m}$ , such as less than 400  $\mu\text{m}$ , such as less than 300  $\mu\text{m}$ , such as less than 250  $\mu\text{m}$ , preferably less than 250  $\mu\text{m}$ , such as less than 200  $\mu\text{m}$ , such as less than 125  $\mu\text{m}$ , such as less than 100  $\mu\text{m}$ , or even less than 50  $\mu\text{m}$ , such as less than 25  $\mu\text{m}$ .

25 Hereby, a minimum of encapsulation material may be used, thus reducing the cost of the microsystem packaging, and, further, the overall size of the microsystem is not remarkably increased.

In a third aspect, the present invention relates to an encapsulation for a three-  
30 dimensional microsystem having an outer surface, said encapsulation covering at least a part of the outer surface of the microsystem, the encapsulation comprising



- a first layer of a first material, said first layer defining a first interface region with the outer surface of the three-dimensional microsystem,
  - a second layer of a second material, said second layer being held by the first  
5 layer and defining a second interface region with said first layer, and
  - a third layer of a third material having an outer surface, said third layer being held by the second layer and defining a third interface region with said second layer.
- 10 The first layer may comprise a non-conducting material, the second layer may comprise a first conducting material and the third layer may comprise a second conducting material. The second layer may further comprise a seed layer so as to increase adhesion of the third layer.
- 15 In a fourth aspect, the present invention relates to a method for encapsulating a three dimensional microsystem having an outer surface, said method comprising the steps of
- providing a first layer of a first material onto at least part of the outer surface of  
20 the microsystem,
  - providing a second layer of a second material onto the first layer, and
  - rotating the three dimensional microsystem around at least a first and a second  
25 rotation axis while providing at least one of the first and second layers, said at least first and second rotation axis intersecting the three dimensional microsystem, and wherein the first axis is different from the second axis.

In a fifth aspect, the present invention relates to a method for encapsulating a  
30 three dimensional microsystem having an outer surface, said method comprising the steps of

- providing a layer onto at least part of the outer surface of the microsystem, said layer comprising a plurality of materials,
  - rotating the three dimensional microsystem around at least a first and a second  
5 rotation axis while providing the layer and varying the material composition of the provided layer as a function of time, wherein the at least first and second rotation axis intersects the three dimensional microsystem, and wherein the first axis is different from the second axis.
- 10 In a sixth aspect, the present invention relates to a method for encapsulating a three dimensional microsystem having an outer surface, said method comprising the steps of
- providing means for providing a first and a second layer onto at least part of the  
15 outer surface of the microsystem,
  - providing the first layer of a first material onto at least part of the outer surface of the microsystem,
  - 20 - providing the second layer of a second material onto the first layer, and
  - rotating, while providing the first and second layer, the three dimensional microsystem and the means for providing the first and second layer relative to each other, the rotation being performed around at least a first and a second axis,  
25 wherein the first axis is different from the second axis.
- In a seventh aspect, the present invention relates to a method for encapsulating a three dimensional microsystem having an outer surface, said method comprising the steps of
- 30
- providing means for providing a layer onto at least part of the outer surface of the microsystem, said layer comprising a plurality of materials,

- providing the layer onto at least part of the outer surface of the microsystem,
- rotating, while providing the layer, the three dimensional microsystem and the means for providing the layer relative to each other around at least a first and a
- 5 second axis, wherein the first axis is different from the second axis.

Regarding the fourth, fifth sixth and seventh aspects, the at least first and second axis may be substantially perpendicular to each other.

- 10 The materials to be used for the encapsulation of the microsystem may be carefully chosen to make sure that optimum protection of the microsystem is achieved. For example, each of the layers of the encapsulation or each part of the one layer of material having a varying material composition may possess different material properties and different material characteristics, and thereby each layer or
- 15 each part of the one layer may have a specific function. The combination of the materials may furthermore provide synergy effects, i. e for example one layer acting as seed layer for another layer, etc., whereby the overall properties of the encapsulation may be improved.
- 20 Furthermore, for the encapsulation to be able to withstand harsh environment a certain thickness of the encapsulation material is needed both because a tight film without pinholes is needed and because, other things being equal, longer time is needed to etch through a thicker film.
- 25 At least one of the layers of the protective encapsulation may comprise a conductive material to shield E-fields. Pure metals having high conductivity values, for example Ag having a conductivity of  $62 \times 10^6$  S/m and Ni having a conductivity value of  $14 \times 10^6$  S/m may be used as conductive material. Furthermore, alloys having high conductivity values may be used, for example Heusler alloy
- 30 (61Cu26Mn13Al) having a conductivity value of  $14 \times 10^6$  S/m or Superalloy (79Ni16Fe5Mo) having a conductivity value of  $1.7 \times 10^6$  S/m may be used.

Furthermore, in order to shield for H-fields at least one of the layers may comprise a material with a relative magnetic permeability between 100 and 1000, for example such as larger than 100, such as larger than 200, such as larger than 300, such as larger than 500, such as larger than 750, such as larger than 1000, 5 or the relative magnetic permeability may even be larger than 1000. Some pure metals have a high relative permeability ( $\mu$ ), for example Fe having a relative permeability of 1000 and Ni having a relative permeability of 250. Furthermore, alloys may be used, such as Heusler alloy having a relative permeability of 800, such as Superalloy having a relative permeability of 100000, etc. Ni containing 10 materials have the further advantage that the durability against chemical attacks is relatively high.

It is envisaged that any metal or alloy having a high conductivity value and/or a high relative permeability may be used.

15

Another layer may comprise a non-conductive material. Typically, the non-conducting layer is the layer closest to the microsystem. The layer may be for example a Teflon® layer, a hydrocarbon containing layer, a parylene layer, etc. The layer may be a thin layer such as a layer having a thickness between 5  $\mu\text{m}$  20 and 50  $\mu\text{m}$ , such as a layer having a thickness below 50  $\mu\text{m}$ , such as below 25  $\mu\text{m}$ , preferably such as below 20  $\mu\text{m}$ , such as below 10  $\mu\text{m}$ , or even more preferred approximately 5  $\mu\text{m}$ . Typically, the microsystem comprises silicon chips, the silicon chips having very sharp edges and/or corners. It may by conventional coating materials and techniques be difficult to coat these sharp edges and/or 25 corners. By choosing a material having a low viscosity and/or a low surface tension, these edges and/or corners may be coated, for example by applying a dip coating process, for applying the first layer. Hereby, the corners and edges are softened so that application of additional conformal layers are facilitated even with processes not suitable for covering of sharp corners and edges.

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Furthermore, hydrocarbons like the GURONIC®, a group of materials from Paul Jordan, Electrotechnische Fabrik GmbH & Co., may be applied by e.g. a dipping

technique. The GURONIC® materials are soft and water-repellent and therefore suitable for the first layer of material to absorb shock and vibrations, and furthermore the materials are suitable for the outer protective layer because of their water-repellent characteristics.

5

Still further, parylene materials poly(chloro-p-xylylene) may be a group of polymers suitable for protective coating of microsystems and microelectronics in general. During a vacuum process, the dimer is evaporated to form a monomer and the monomer condenses on the sample where it polymerizes. The process may be  
10 undertaken at room temperature, and the thickness of the parylene layers are typically between 5  $\mu\text{m}$  and 25  $\mu\text{m}$ , for example such as less than 25  $\mu\text{m}$ , such as less than 15  $\mu\text{m}$ , preferably such as less than 10  $\mu\text{m}$ , for example such as about 5  $\mu\text{m}$ . The parylene layer may be substantially pinhole free, and is furthermore a very tight and durable material in itself.

15

In addition, in order to prevent water penetrating the encapsulation, at least one of the layers may comprise a material having a water permeability between  $10^{-19}$  g/cm·s·torr and  $10^{-9}$  g/cm·s·torr, such as below  $10^{-9}$  g/cm·s·torr, such as less than  $10^{-11}$  g/cm·s·torr, such as less than  $10^{-13}$  g/cm·s·torr, preferably less than  $10^{-15}$   
20 g/cm·s·torr, such as less than  $10^{-17}$  g/cm·s·torr, such as below  $10^{-19}$  g/cm·s·torr. Materials like e.g. plated metals like Ni and Au and furthermore electroless Ni are tight encapsulation materials because they are amorphous and therefore grain boundary water diffusion will be limited.

25 The encapsulation may comprise a variety of materials e.g.: semiconductors, ceramics, oxides, metals, polymers, hydrocarbons, and silicones.

The encapsulation may further comprise at least one layer that protects the microsystem against light.

30

The microsystem may be completely encapsulated with at least one layer of material. Alternatively, the encapsulation may have one or more openings each of

said one or more openings extending from an outermost surface of the encapsulation to the outer surface of the microsystem.

The above-mentioned openings may be adapted for different applications. Some  
5 of the one or more openings may be adapted for passing fluids to and from the microsystem. Some of the one or more openings may alternatively or additionally be adapted for transmitting electrical signals to and from the microsystem. Finally, some of the one or more openings may be adapted for transmitting pressure, such as an air pressure or a liquid pressure, to the microsystem.

10

Each layer of the encapsulation or each of the materials of the encapsulation may be designed for a specific use, i.e. to protect the microsystem against penetrating water, shielding the microsystem against EMI E-fields, and/or against magnetic H-fields, etc. Furthermore, more layers may be used, such as 4, 5, 6 and 7 layers,  
15 and even up to 10 and 15 layers may be used, and further each layer may comprise for example a first and a second material, the materials being distributed in a sandwich structure, comprising up to 10, 20 or as many as 50 or even up to 100 alternating structures. Repetitions of the layer structures may be more effective than single layers of materials for example for EMI E-field shielding since  
20 the most effective E-field damping takes place at the interface between these layers by reflection.

Traditionally, polymer chip encapsulation is performed with quarts filled epoxies by injection/transfer moulding at pressures and temperatures too high for direct  
25 contact with the microsystems of concern. The minimum thickness of the material is due to the processing methods limited to around 0.25 mm. Alternatively, more gentle encapsulation processes, such as spraying and/or dipping may be applied. By spraying the encapsulation material onto the microsystem, several advantages may be obtained.

30

For example, by spraying encapsulation material onto the microsystem, the amount of applied material may be controlled. Furthermore, even badly adhering materials may be applied. The materials to be sprayed onto the microsystem

should preferably have a relatively low viscosity to enable spraying of the materials. Alternatively, the materials may be diluted so as to obtain a material having a viscosity suitable for spraying. The viscosity suitable for spraying depend upon the spraying equipment used, but, typically, a viscosity suitable for spraying  
5 may be less than 5 Pascal-second, such as less than 1 Pascal-second, for example such as approximately 0,7 Pascal-second.

To avoid shadowing effects, the microsystem and/or the spray nozzle may be kept in specific positions so as to avoid the shadowing effects, and for example avoid  
10 keeping the spray nozzle and the microsystem in stationary positions.

Another example of a process suitable for encapsulation of microsystems is a dipping process, the dipping process being a fairly simple process, and again the materials to be used should preferably have a relatively low viscosity or the  
15 materials should be diluted so as to obtain a material having a relatively low viscosity.

Both the spraying process and the dipping process may be used at ambient pressures and temperatures.  
20

By using a dipping process the applied amount is controlled primarily by the surface tension of the selected materials which may result in a coating having an uneven thickness, i.e. a coating being thinnest at the corners of the structures, thus, lowering the reproducibility of the process. To obtain a more conformal  
25 coating, the microsystem with the newly applied material may be spinned so as to ensure a proper distribution of the material.

Furthermore, to avoid the thinning effect at the very steep corners, an alternative design of the corners may be used. The very sharp corners and edges may e.g.  
30 be softened by applying a step structure so that each corner comprises one or more steps, i.e. two or more corners.

By using a spraying process the applied amount of material is more easily controlled, and by paying attention to the shadowing problem, i.e. the problem that some parts of the system may not be exposed to the applied material due to shadowing by the system itself, the process may be well controlled. It is  
5 furthermore important to control the creation of drops on the surface of the microsystem to be spray coated.

To spray coat a first layer of for example Teflon® may be a difficult task due to the poor wetting of the first Teflon® layer. However, by adapting the application speed  
10 of the material, the droplets may be allowed to cure and/or dry sufficiently fast upon impact with the surface. In this way retraction of the material because of poor wetting is avoided. Thus, by choosing the application speed for the specific application, coating of the Teflon® layer may be accomplished.

15 To obtain a well controlled process, the microsystem may be rotated around one or more axes whereby excess material may be removed and/or forced to move to uncovered or badly covered areas e.g. corners, edges, and surfaces difficult to wet. Alternatively, the spray nozzle may be rotated around the microsystem or the microsystem may rotate around one or more axes while the spray nozzle rotates  
20 around the microsystem during deposition. In this way by automatically rotating both the microsystem and the spray nozzle during deposition the shadowing effect may be significantly reduced during the spraying process and an improved reproducibility may be obtained.

25 Since the thickness of the coatings may be down to a few tenth of a mm, particles in the environment during processing may cause for example pinholes and other severe problems for the quality of the coating to occur in the encapsulation, and therefore, the processes are preferably undertaken in clean room environments.

30 In order to obtain a smooth conformal coating, it is preferred to use materials having a low viscosity and/or a low surface tension, or, alternatively, materials that



may be diluted and/or dissolved so as to lower the viscosity and/or the surface tension of the materials.

Another process for applying polymer materials to form an encapsulation of the  
5 microsystem may be fluidised bed coating. In this process air is blown through powder of the material to make the powder behave like a liquid. The powder particles then melt on the surface of the immersed preheated sample. The material may be applied in thickness' from 0.1 mm and up.

10 When metallizing a non-conductive surface, a number of application techniques may be applied, for example galvanic plating, electroless plating, spraying, dipping, Physical Vapour Deposition (PVD), Low Temperature Arc Vapour Deposition (LTAVD), Chemical Vapour Deposition (CVD), etc. In some cases the purpose of the deposited conductive layer (seed layer) is to make it possible to  
15 galvanically plate afterwards and/or to get a better adhesion of the plated material. Some of the techniques are directional (e.g. spray, PVD) so that shadowing may occur due to the way the material is supplied during deposition. Rotation of the sample and/or the source of material supply may be able to at least reduce problem.

20

The materials relevant for application of a conductive layer on three-dimensional microsystems are numerous, the materials may be certain polymers (e.g. polyaniline), polymers containing fillers, the fillers comprising conductive particles, semiconducting materials, certain ceramics, such as for example TiN deposited by  
25 ECRPCVD (Electron Cyclotron Resonance Plasma Chemical Vapour Deposition) and/or metals. Amorphous continuous layers achieved by using electroless plating are preferred because they may be tight, i.e. substantially pinhole free and are generally more durable towards chemical attacks.

30 A chemical attack on the microsystems may for example be mainly due to encapsulated water or water penetrating the encapsulation of the microsystem. Hereby, mainly the microsystem is affected whereas the encapsulation material may not be severely affected. The microsystem may also be exposed to harsh

media attacking both the encapsulation materials and the microsystem underneath. In many sensor microsystems, it is therefore advantageously that the encapsulation materials themselves are highly durable towards chemical attacks.

There are several material factors that generally increase resistance to humidity,

5 some of those are:

- 1) Low water transmission and equilibrium absorption
- 2) Low ionic content
- 3) Low hydrolysis
- 10 4) Low plasticization by water
- 5) Low polar content
- 6) Good adhesion to fillers
- 7) Low moisture absorption by fillers
- 8) Low change on exposure to heat and contaminants
- 15 9) Low internal stress

It is, thus, important that there are no means in the material that absorbs the water, and further, if water should be absorbed by the encapsulation materials, it is important that the water is not transported to the first interface region by means of,  
20 for example, ions in the encapsulation material. It is furthermore advantageous that the encapsulation material has a good adhesion to fillers that may be contained in the encapsulation material so as not to allow water to migrate in boundary surfaces of bad adhesion between the encapsulating material and the fillers.

25

Physical attacks such as shock and wear may also often be considered very important. The factors that increase the resistance of the encapsulation materials and the resistance of the microsystems are in these cases their softness, hardness and ductility, respectively. The E-field EMI shielding becomes more and  
30 more important and shielding may be accomplished by use of conductive materials. Highly conductive materials are good shields against E-fields, and in many cases the material may preferably also have a high magnetic permeability to shield H-fields effectively.

Furthermore, other than the intrinsic properties of the materials may be evaluated when the materials are to be used for encapsulation of microsystems. Also to be considered when choosing the optimum material is the amount of material to be used, the interaction between the material and the microsystem, and further how the material may be applied. That is, also the following factors should be considered when talking about factors enhancing resistance to water:

- 10) Large amount encapsulation material
- 10 11) Low stress coupling
- 12) Good adhesion
- 13) Low chemical / physical change of protected system by water

If the material, for example, has a high stress coupling, it would be likely that cracks would occur when the microsystem and the encapsulation are affected by the environments so that water would be able to migrate through the encapsulation material to the outer surface of microsystem, so, therefore, a low stress coupling may be preferred.

- 20 The microsystem encapsulation materials properties may preferably fulfil a number of criteria, either each material as such or the combination of the materials. The encapsulation should be chemically durable, have a bulk water and/or gas tightness, and have an interface water tightness. Furthermore, the encapsulation material(s) and the microsystem materials should be compatible, for example with regard to thermal expansion, stress couplings, etc. Still further, the encapsulation material(s) should preferably form a conformal and thin coverage of the microsystem, and still preferably be applicable by a gentle application method.

The chemical durability and bulk water tightness are even more important when encapsulating microsystems, such as multichip microsystems, than when encapsulating traditional ICs with polymers, for example by applying a globtop, since the coatings according to the present invention are much thinner - of the order of a few tenths of a mm, see above. These factors represent severe

constraints on the range of materials that may be used. In many cases traditional encapsulation materials like quartz/glass-filled epoxies and injection/transfer moulding techniques are not suitable due to the implied high pressures and temperatures during processing. Choosing a very chemically inert material results  
5 often in a material having a less good adhesion which again may result in a poor water tightness. Generally, polymers are less water tight than materials like glasses and metals, see Figure 6. On the other hand polymers, such as fluorocarbons, may be more chemically durable than most pure metals, alloys and ceramics. The drawback for fluorocarbons may be that they, due to their very low  
10 surface tension and strong C-F bonds, in many cases adhere badly to most materials.

The surface tension is an important parameter since it has a great influence on whether it is possible to make a conformal and thin (between 5  $\mu\text{m}$  and 500  $\mu\text{m}$ ,  
15 such as between 10  $\mu\text{m}$  and 500  $\mu\text{m}$ ) coverage of the multichip microsystem with avoidance of entrapped air. The adaptation of the coverage to the shape of the microsystem is a very critical issue, since microsystems often are made of single crystalline silicon that results in very sharp corners which may be difficult to cover.

20 Preferably, the encapsulation material(s) should also be chemically and physically compatible with the other materials of the microsystem, not e.g. dissolving any of the materials nor introducing too much stress, etc. Typically, the microsystem comprises Silicon and/or other semiconductor materials, ceramics, polymers, such as polyimides, epoxies, silicones, etc, and metals.

25

Polymers in the microsystems may be difficult to wet due to their low surface energy and they may be the materials most chemically sensitive e.g. toward solvents in the coating materials. Therefore, polymers represent the biggest challenge concerning chemical compatibility. Polymers may typically be used for  
30 encapsulation and underfilling, support of interconnections, such as flex prints, flexible silicon, and other attachments, etc. The larger the exposed polymer area relative to easily wettable areas, the more difficult it may be to cover that area with

a small amount of material and at the same time avoid air entrapment. Typically, the largest areas are represented by polymer encapsulated ICs and insulating materials on interconnections.

- 5 Typically, the encapsulation materials suitable for encapsulating electronics are not so tight that it is ensured that the performance will not be affected more or less severely by chemicals penetrating through the encapsulation during the service time of interest. There are no general leak rate limits to ensure proper performance within lifetimes of interest since the allowable leak rate depends on
- 10 the penetrating chemical and on the exact system considered. Furthermore, it is difficult to correlate between leak rates of different chemicals. Often when interested in the leak rate of water the measurement is made on helium.

- Polymers, even when modified by fillers, etc., have a relatively poor water
- 15 tightness and a high Coefficient of Thermal Expansion (CTE) compared to the silicon in the microsystem . making them less suitable for microelectronics encapsulation purposes. However, due to their low price and ease of handling polymers are very attractive.

- 20 It is often impossible to find one encapsulation material which sufficiently protects for all of the above-mentioned areas at the same time. It is therefore preferred to combine different materials having different material properties so that the encapsulation of the microsystem comprises one or more layers of material.

- 25 In the case where water tightness is a problem, adhesion may be promoted by using a suitable encapsulation material, such as an encapsulation material comprising silane with organic / inorganic chemical coupling groups and/or by roughening, activating, priming and/or cleaning of the adhesion surface by e.g. plasma treatment, such as cold oxygen plasma treatment, etc so as to increase
- 30 the surface tension and reactivity of especially polymers thereby also increasing the adhesion of applied polymeric coatings. Furthermore, sealing of the surface by for example applying an epoxy material at the critical areas may be used.

Example of layer structures and processes to fulfil the demands in the previously described are presented in the following. As described the sensitivity of the microsystems and the choice of materials strongly affects the application methods that can be used.

5

## BRIEF DESCRIPTION OF THE DRAWING

Figure 1 shows examples of devices that may be encapsulated according to the present invention,

10

Figure 2 shows further examples of devices that may be encapsulated according to the present invention,

In Figure 3 two embodiments, L, M, wherein an microsystem as well as an  
15 integrated circuit (IC) are encapsulated according to the present invention,

Figure 4 shows details of the coatings of an encapsulated device,

Figure 5 illustrates an embodiment, O, with air entrapped within the encapsulation  
20 and an embodiment, P, with underfilling and attachment material,

Figure 6 shows an embodiment having flexible silicon interconnections

In Figure 7 the permeability for various materials such as silicon and glasses are  
25 shown,

Figure 8 shows the variation in thickness of the encapsulation depending on how the encapsulation is performed,

30 Figure 9 illustrates an example of how the encapsulation can be applied, and

Figure 10 shows the variation in a graded composition of a layer in an encapsulated microsystem.

## DETAILED DESCRIPTION OF THE DRAWING

In Figure 1 and Figure 2 examples of devices that may be encapsulated are shown. The device to be encapsulated may have the microelectronics integrated  
5 with the sensor or the sensor may have the microelectronics included as a separate part. Examples of both cases are shown in Figure 1 A-H. The microelectronics and the sensor may be interconnected via for example bonding wires as shown in device I.

- 10 The microsystem may thus comprise several elements, each element having a functionality, such as the microsystem 1, the microelectronics 6, the one or more openings 2, one or more interconnecting and/or carrying chips or parts.

Thus, the device to be encapsulated may be an microsystem for measuring:

15

- Absolute / relative pressure, sound pressure such as A, E,
- Differential pressure / flow (fluid) / chemical composition such as B, F,
- Light (flow / chemical composition etc.) such as C, G,
- Acceleration (D, H, I).

20

In Figure 1, the microsystem/transducers 1 have one or more windows or openings 2 (tube 20, transparent material 21, sensing material (not shown)) through which the surroundings have an effect on the microsystem 1, 3 is the window mounting material, 4 is a signal in/out wire, 5 are electrical  
25 interconnections (solderings, conductive adhesives, flip-chips, etc.), 6 is an ASIC or other microelectronic component, 7 is a supporting substrate, leadframe etc., 8 is a bondpad and 9 is a bondwire.

In many cases the measurement is performed through a certain port in the  
30 microsystem. In Figure 1 (A, B, E and F) a little tube 2 leads the pressure (from e.g. gas, liquid, sound) or material to/past a sensing area on the microsystem. In C and G an optical window of e.g. glass is connected with the microsystem. The

optical window may further be connected to e.g. tubes leading a substance to be analysed past the window. The tube or window material and therefore the mounting material as well as the mounting method may vary, and the tube may even be an integrated part of the microsystem.

5

Figure 1 (D and H) illustrate the cases where a port is not required e.g. when measuring acceleration. Other microsystems may be similar to these figures e.g. relays, switches etc.

- 10 In all of the figures the output signal from either an Application Specific Integrated Circuit (ASIC) or integrated microelectronics is transferred through soldered wires, though it could just as well be a soldered and/or glued flex prints, bond wires, one or more optical fibres, etc. The devices I, J and K, in Figure 2 illustrate various connections, such as a bond wire 9, a flex print 10, a soldering/gluing 11, an  
15 optical fibre 12, and a fibre interconnection 13.

Figure 3 shows two embodiments (L and M) of an encapsulated multichip microsystem. In a first embodiment, L, an encapsulated device like E in Figure 1 has been coated with a first conducting layer 14. The conducting layer serves as  
20 an EMI shield while at the same time enhancing the physical durability of the microsystem. The layer has been applied by spraying.

In the embodiment, M, the outer plated metal layer 15 is e.g. a Fe-containing layer having a high conductivity and a high magnetic permeability, and is applied on top  
25 of the first Teflon® layer 14. The outer layer serves as an EMI E-field and H-field shield while at the same time enhancing the overall water tightness and chemical and physical durability of the encapsulation by several orders of magnitude. The polymer underneath primarily serves as a highly insulating, stress and shock  
30 parts on the surface of the microsystem and the integrated circuit. The actual composition and application of the two layers are described in the following case 1.



In a third embodiment, N in Figure 4, an encapsulation like in case 2 is illustrated. Figure 4 shows how the two layers follow the shape of the microsystem closely. In the close up 1) of the two layers the arrows illustrate how e.g. chemicals and water may penetrate the encapsulation. At openings of the layer, as shown in the close up 2), it appears that e.g. water or chemicals may easily enter especially when adhesion is bad. This can be avoided by providing the encapsulation with a sealing as shown in the close up 3) where the black area represents the sealing at the opening of the coatings e.g. where a flex print made of polyimide comes out. In case the bottom layer is Teflon® and the top layer is metal there will be a bad  
10 adhesion between polyimide and Teflon® and between Teflon® and metal. By applying e.g. epoxy over the exposed open interfaces the amount of water capable of entering will be limited significantly since epoxies adheres much better to polyimide than Teflon® and very well to metals. Depending on the exact situation the sealing can cover the complete three-dimensional multichip  
15 microsystems as a coating. This may be relevant when the metal layer is less resistant to corrosion and needs to be protected.

A first interface region 30 is thus formed between an outer surface 33 of the microsystem 1 and the first layer 14 of a first material and a second interface  
20 region 35 is formed between the first layer of material 14 and the second layer of material 15. Furthermore, a third interface region 31 is formed between the second 15 and third 17 layer of material. The outermost surface 37 of the encapsulation material is thus the outer surface of the third layer of encapsulation material 17

25 In O in Figure 5, an example of air 40 entrapped due to the lack of coating material 14 in the space between the IC and the microsystem and the microsystem and the flex print is shown. Instead of having the material 14 to fill out the gaps, a specific underfill material might have been used to avoid the entrapped air. Having air gaps in the encapsulation material may e.g. lead to development of delamination  
30 and cracks in the encapsulation if e.g. the ambient pressure changes. In a fourth embodiment, P in Figure 5, underfilling 42 is used, and it is seen that underfill material 42 and attachment material 44 are not highly exposed to the coating 14,

15. At positions where they are in contact it is crucial that the materials are compatible.

In Fig. 6 an embodiment is shown wherein different parts 50, 51, 52, 53 of the  
5 microsystem are mechanically interconnected via flexible silicon parts 54. By  
applying electrically conductive material 55 on the flexible silicon parts, also  
electrically interconnection is achieved. The different parts 50-53 of the  
microsystem may be flip-chip bonded to the substrate, the flip-chip bumps 60  
being the interconnection between the different parts 50-53 and the silicon  
10 substrate. To achieve microsystems having a small a volume as possible, the  
different components/elements of the microsystem may be mounted on an  
interconnection substrate with regions which may be bended. By having a single  
substrate carrying the different components/elements of the microsystem and at  
the same time interconnecting the different parts, optimal compatibility between  
15 the materials of the structure and minimal size is achieved.

Figure 7 shows the time for the interior of a package to reach 50% of exterior  
humidity depending on the thickness of the material as well as the permeability of  
the material. From the figure it appears that materials such as silicones and  
20 epoxies are less tight to water than e.g. glasses and metals. Furthermore, it  
appears that the thickness of the material also influence on the time for interior of  
the package to reach the 50% humidity, i.e. a thicker material is a better protection  
towards water than a thinner material.

25 In Figure 8, the thickness of an encapsulated single crystalline silicon chip 81 is  
shown. A dipping process has been used for application of the encapsulation 80 in  
Figure 8a. From the figure, it appears that the coating is thinner at the corners and  
the edges 83 than at the rest of the sides of the chip. In Figure 8b the  
encapsulation has been applied by e.g. rotating the silicon chip 81 during coating.  
30 It appears that by rotating the chip the thickness of the encapsulation 80 is more  
uniform.

A way to obtain this is illustrated in Figure 9, where an microsystem is rotated around a first 90 and a second 91 axis while providing the material by providing means, such as a spray nozzle, 20. A temporary lid 93 is provided so as to ensure that the opening 2 is not encapsulated.

5

To be able to predict the behaviour of the materials on a specific microsystem, simulations may be performed to, dependant of the material properties of the encapsulation materials and the structure of the microsystem, predict the distribution of the materials. Preferably, the public domain software 'Surface

10 Evolver' is used.

Instead of encapsulating the microsystem with a plurality of layers, a single layer with a graded composition of two or more materials or phases may be applied. In Figure 10 an example of how the composition of the two components varies as a  
15 function of the distance to the surface of the microsystem i.e. from a first interface region to an outer surface of the encapsulation. The materials within the encapsulation layer may be multiphase materials (composites) such as blends of immiscible polymers or polymers with fillers. When blends of immiscible polymers are used the relative amount of each component could be varied e.g. by a suitable  
20 mixing apparatus e.g. a spraying equipment.

For polymers with fillers (e.g. ceramic and metal powder) the fillers normally distribute randomly in the matrix material. However, due to gravity the fillers may gather near one of the surfaces of the polymer so that the layer becomes graded.

25

In case the coating is thin and therefore not graded in composition it can be made so by applying more of the matrix component. Also reacting materials like e.g. multi chemical component systems such as 2 component epoxy may be used. The relative amount and / or chemical structure of the reacting components are varied  
30 e.g. by suitable mixing equipment before e.g. spraying. A way to do this could be by using spray nozzles for two component mixing from the company "Spraying Systems Co" together with standard flow meters and pressure gauges for control and monitoring of the supplied amount of each component.

Below a number of cases with different combinations of layers are shown, wherein the layers are applied by e.g. one or more of the application techniques described earlier. All the selected examples illustrate situations where first an insulating layer  
5 is applied and thereafter a conducting layer.

### Case 1

Example of a two layer structure. The first layer is a highly insulating and  
10 chemically durable Teflon® layer. The second layer is conductive and serves primarily as an EMI shielding layer. The second layer is also an example of a layer with a graded composition.

#### 1. layer.

15 5 times dipping in 5 wt% Teflon® AF 1600 (4,5-difluoro-2,2-bis(trifluoromethyl)-1,3-dioxole with tetrafluoroethylene) dissolved in fluorinert FC 75 (perfluoro(2-butyltetrahydrofuran)) with drying at room temperature for at least 1 hour between each dip. The Teflon® AF 1600 is from DuPont and is preferable dissolved by applying ultrasound for at least 2 hours after mixing. It can be dissolved up to 10  
20 wt% at room temperature. To ensure that all the fluorinert FC 75 has evaporated the coating may be baked following the recipe recommended by DuPont: i.e. 5-10 min. at 50 °C, 5-10 min. at 110 °C, 5 min. at 165 °C. After that 10-15 min. at 330 °C ensures optimum uniformity of coating thickness and adhesion. To further enhance adhesion of Teflon® AF 1600 to silicon perfluorosilanes like 1H, 1H, 2H,  
25 2H-perfluorodecyltriethoxysilane can be used..

Resulting layer thickness on single crystalline silicon chips is around 150 µm at flat surfaces and 50 µm at sharp corners.

#### 30 2. layer.

Spraying with Chomerics 2052, which is an acrylate loaded with silver plated Cu particles having a diameter of maximum 40 µm.

A thin layer of about 25  $\mu\text{m}$  is applied. The layer is dried for at least 2 hours at room temperature. This layer will give a minimum E-field attenuation of 30 dB in the frequency range 30 MHz - 1 GHz. Applying a second layer after drying of the first layer results in a total Chomerics 2052 thickness of approx. 150  $\mu\text{m}$  which provides E-field attenuation of minimum 55 dB in the frequency range 30 MHz - 1 GHz.

### Case 2

10

This is an example of a 3 layer structure where the second layer acts as a seed and/or adhesion layer for the final plated layer, 3. layer.

1. layer.

15 A Teflon <sup>®</sup> layer as in case 1.

2. layer.

Spraying with Demetron leitsilber 200, nitrocellulose dissolved in ethoxypropanole and acetone and loaded with Ag particles. After application, the ethoxypropanole and acetone evaporates leaving the silver particles locked at the surface in the nitrocellulose and thus exposed to the surroundings and suitable for plating.

20

3. layer.

Plated Cu, Ni, Cu...Ni, Au

25 Plated  $\mu$ -metal, Au

### Case 3

This is an example of a three layer structure where the second layer acts as a seed and/or adhesion layer as described earlier for the last plated layer. Electrical contact to the seed layer is accomplished by having an opening in e.g. the flex print close to the microsystem.

30

1. layer.

A Teflon® layer as in case 1

5 2. layer.

Spraying with conducting polymers ORMECON L5006, polyaniline in an acrylic binder system.

3. layer

10 Plated layer as in case 2

#### Case 4

1. layer

A Teflon® layer as in case 1

15

2. layer.

Spraying with conducting polymers ORMECON L5000, polyaniline in a polyamide binder system.

20 3. layer

A plated layer as in case 2

#### Case 5-8

25 The 1. layer of any of the above cases have a UV curable Loctite 394, a two component urethane / acrylate mixture, applied by spraying.

## CLAIMS

1. An encapsulation for a three-dimensional microsystem having an outer surface, said encapsulation covering at least part of the outer surface, the encapsulation  
5 comprising

- a first layer of a first material, said first layer defining a first interface region with the outer surface of the three-dimensional microsystem,

10 - a second layer of a second material having an outer surface, said second layer being held by the first layer and defining a second interface region with said first layer,

wherein the shortest distance between the first and second interface regions is  
15 essentially constant, and wherein the shortest distance between the first interface region and the outer surface of the second layer is essentially constant and between 5  $\mu\text{m}$  and 500  $\mu\text{m}$ .

2. An encapsulation according to claim 1, further comprising a third layer of a third  
20 material being held by the second layer and defining a third interface region with said second layer.

3. An encapsulation according to any of the preceding claims, wherein at least one of the layers comprises a conductive material.

25

4. An encapsulation according to any of the preceding claims, wherein at least one of the layers comprises a non-conductive material.

5. An encapsulation according to any of the preceding claims, wherein at least one  
30 of the layers comprises a material with a relative magnetic permeability between 100 and 1000.

6. An encapsulation according to any of the preceding claims, wherein at least one of the layers comprises a material with a relative magnetic permeability larger than 1000.
- 5 7. An encapsulation according to any of the preceding claims, wherein at least one of the layers comprises a material having a water permeability between  $10^{-9}$  g/cm·s·torr and  $10^{-19}$  g/cm·s·torr.
8. An encapsulation according to any of the preceding claims, wherein one of the  
10 layers comprises a material selected from the group consisting of semiconductors, ceramics, metals, polymers, hydrocarbons.
9. An encapsulation according to claim 8, wherein one of the layers comprises a mixture of materials selected from the group consisting of semiconductors,  
15 ceramics, metals, polymers, hydrocarbons.
10. An encapsulation according to any of the preceding claims, wherein the shortest distance between the first interface region and the second interface region is between 5  $\mu$ m and 250  $\mu$ m.  
20
11. An encapsulation according to any of the preceding claims, wherein the shortest distance between the first interface region and the outer surface of the second layer is essentially constant and between 10  $\mu$ m and 500  $\mu$ m.
- 25 12. An encapsulation according to any of the preceding claims, wherein the microsystem is completely encapsulated with at least one layer of material.
13. An encapsulation according to any of the claims 1-11, said encapsulation having one or more openings each of said one or more openings extending from  
30 an outermost surface of the encapsulation to the outer surface of the microsystem.



14. An encapsulation according to claim 13, wherein a part of the one or more openings are adapted for passing fluids to and from the microsystem.

15. An encapsulation according to claim 13, wherein a part of the one or more  
5 openings are adapted for transmitting electrical signals to and from the microsystem.

16. An encapsulation according to claim 15, wherein a part of the one or more openings are adapted for transmitting air pressure to the microsystem.

10

17. An encapsulation for a three-dimensional microsystem having an outer surface, said encapsulation covering at least part of the outer surface, the encapsulation comprising

15 - a layer comprising a plurality of materials, said layer defining an interface region with the outer surface of the three-dimensional microsystem and having an outer surface, wherein the material composition of the layer, in a region between the interface region and the outer surface of the layer and along a direction defined as the shortest distance between the interface region and the outer surface, varies as  
20 a function of a distance from the interface region.

18. An encapsulation according to claim 17, wherein the plurality of materials comprise a polymer.

25 19. An encapsulation according to claim 18, wherein the polymer comprises a filler.

20. An encapsulation according to claim 19, wherein the filler comprises a material selected from the group consisting of ceramics and metals.

30

21. An encapsulation according to any of claims 17-20, wherein the shortest distance between the interface region and the outer surface is essentially constant and between 5  $\mu\text{m}$  and 500  $\mu\text{m}$ .

5 22. A method for encapsulating a three dimensional microsystem having an outer surface, said method comprising the steps of

- providing a first layer of a first material onto at least part of the outer surface of the microsystem,

10

- providing a second layer of a second material onto the first layer, and

- rotating the three dimensional microsystem around a at least a first and a second rotation axis while providing at least one of the first and second layers, said at

15 least first and second rotation axis intersecting the three dimensional microsystem, and wherein the first axis is different from the second axis.

23. A method according to claim 22, wherein the at least first and second axes are substantially perpendicular to each other.

20

24. A method for encapsulating a three dimensional microsystem having an outer surface, said method comprising the steps of

- providing a layer onto at least part of the outer surface of the microsystem, said  
25 layer comprising a plurality of materials,

- rotating the three dimensional microsystem around at least a first and a second rotation axis while providing the layer and varying the material composition of the provided layer as a function of time, wherein the at least first and second rotation

30 axis intersects the three dimensional microsystem, and wherein the first axis is different from the second axis.

25. A method according to claim 24, wherein the at least first and second axes are substantially perpendicular to each other.

26. A method for encapsulating a three dimensional microsystem having an outer  
5 surface, said method comprising the steps of

- providing means for providing a first and a second layer onto at least part of the outer surface of the microsystem,
- 10 - providing the first layer of a first material onto at least part of the outer surface of the microsystem,
- providing the second layer of a second material onto the first layer, and
- 15 - rotating, while providing the first and second layer, the three dimensional microsystem and the means for providing the first and second layer relative to each other, the rotation being performed around at least a first and a second axis, wherein the first axis is different from the second axis.

20 27. A method according to claim 26, wherein the at least first and second axes are substantially perpendicular to each other.

28. A method for encapsulating a three dimensional microsystem having an outer  
surface, said method comprising the steps of

25

- providing means for providing a layer onto at least part of the outer surface of the microsystem, said layer comprising a plurality of materials,
- providing the layer onto at least part of the outer surface of the microsystem,
- 30 - rotating, while providing the layer, the three dimensional microsystem and the means for providing the layer relative to each other around at least a first and a second axis, wherein the first axis is different from the second axis.

29. A method according to claim 28, wherein the at least first and second axes are substantially perpendicular to each other.

5 30. An encapsulation for a three-dimensional microsystem having an outer surface, said encapsulation comprising for a part of the outer surface of the microsystem

- a first layer of a first material, said first layer defining a first interface region with  
10 the outer surface of the three-dimensional microsystem,

- a second layer of a second material, said second layer being held by the first layer and defining a second interface region with said first layer, and

15 - a third layer of a third material having an outer surface, said third layer being held by the second layer and defining a third interface region with said second layer.

31. An encapsulation according to claim 30, wherein the first layer comprises a non-conducting material, the second layer comprises a first conducting material  
20 and wherein the third layer comprises a second conducting material.

32. An encapsulation according to claim 31, wherein the second layer comprises a seed layer.

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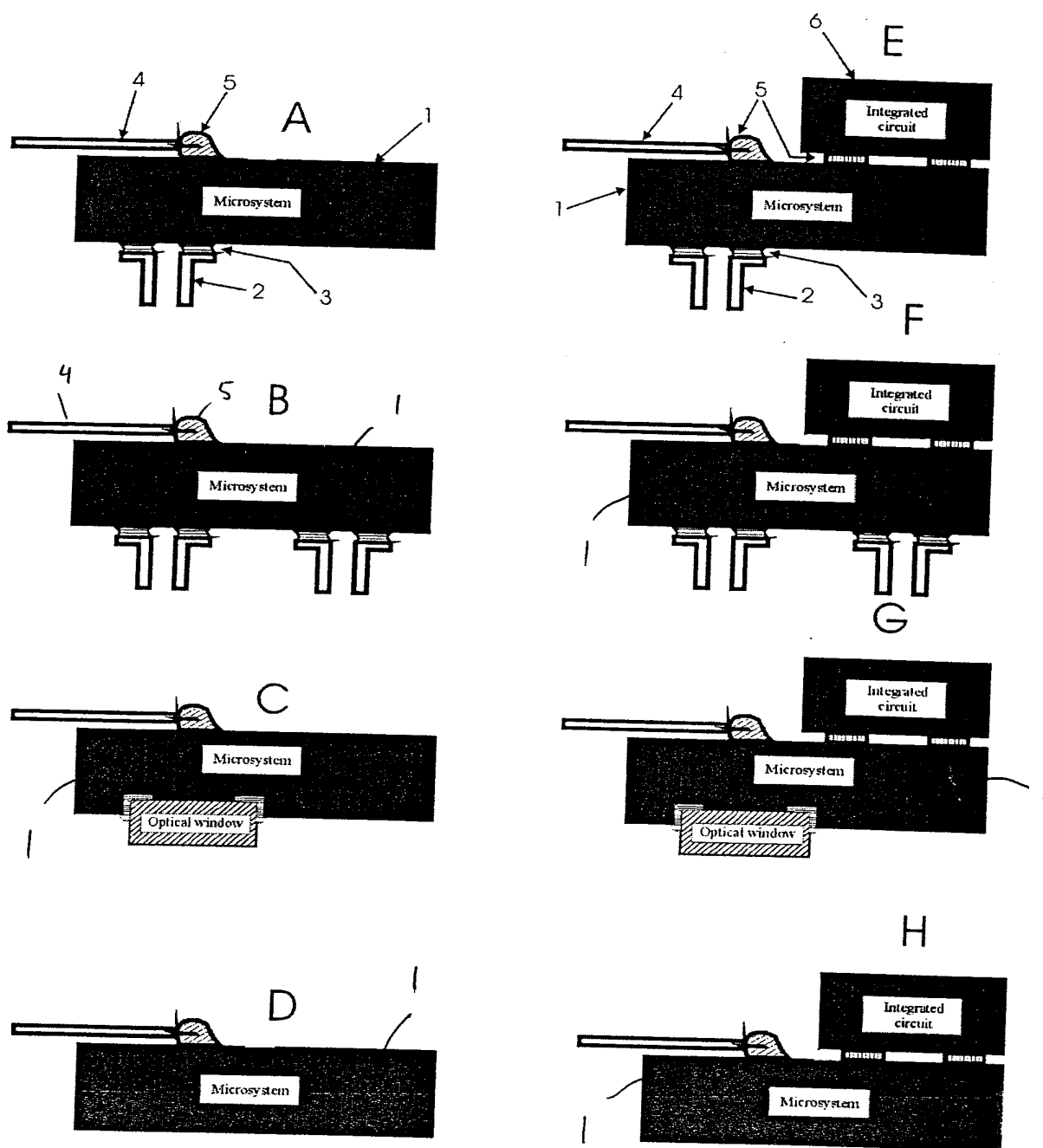


Fig. 1

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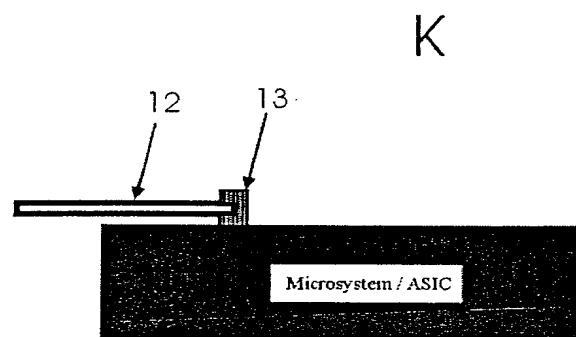
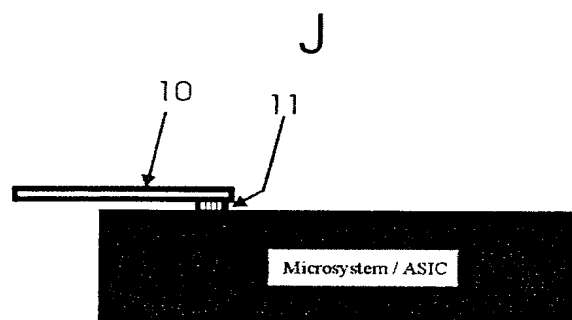
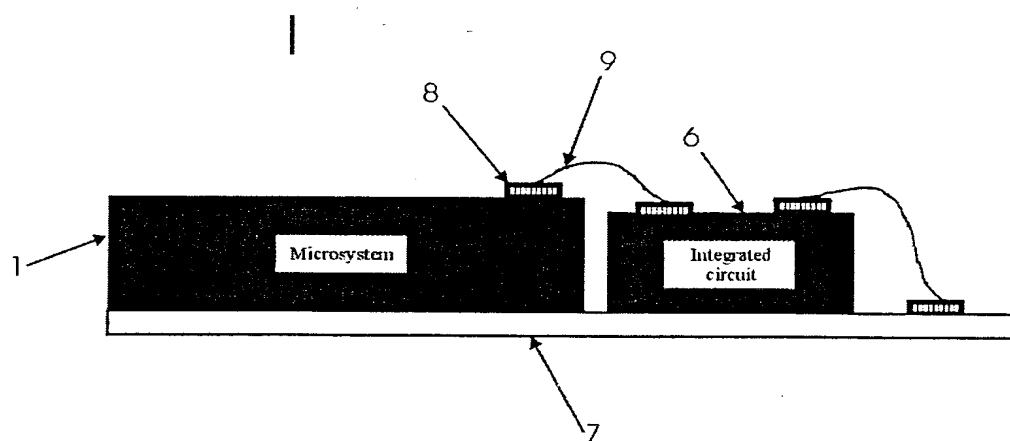
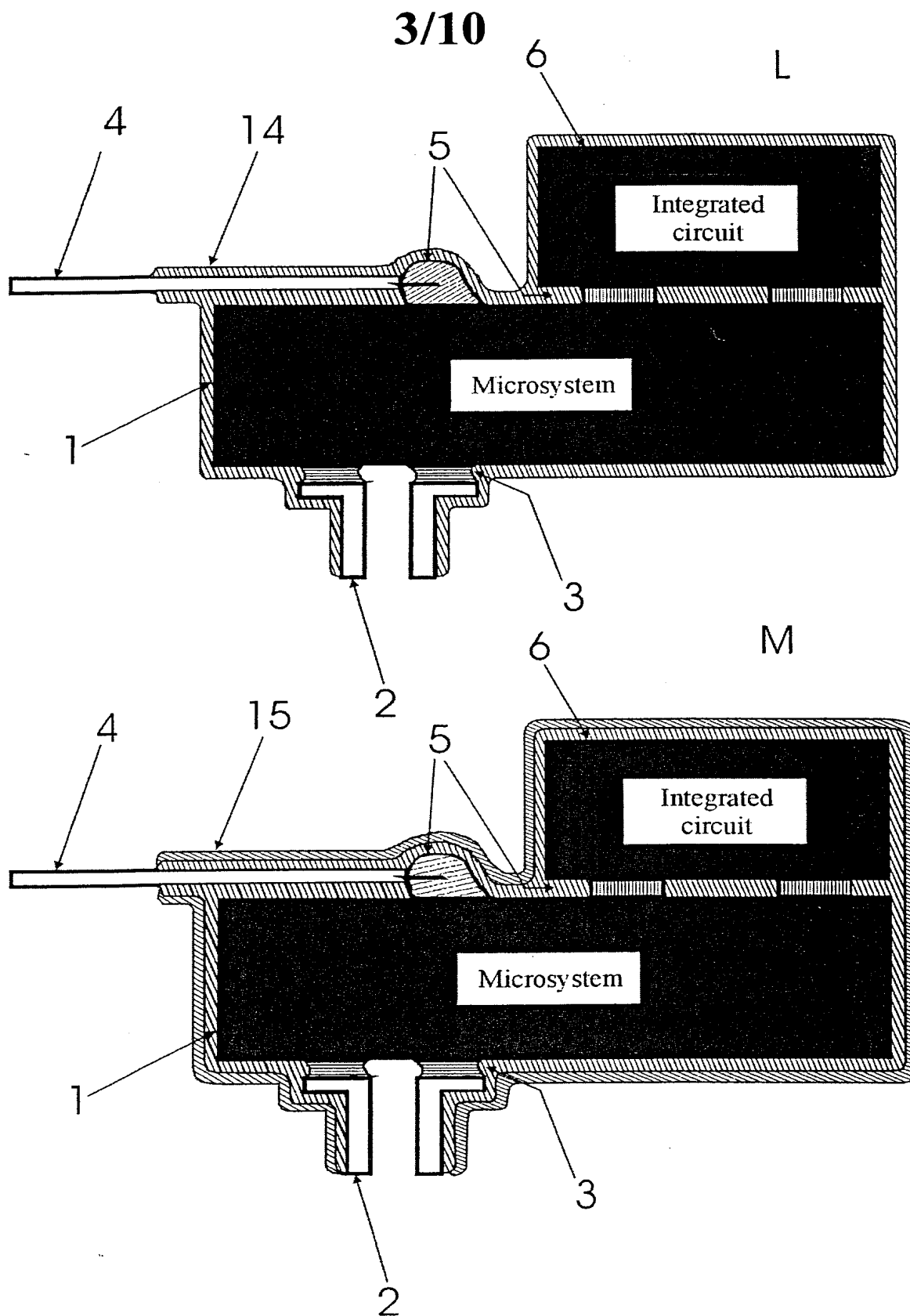
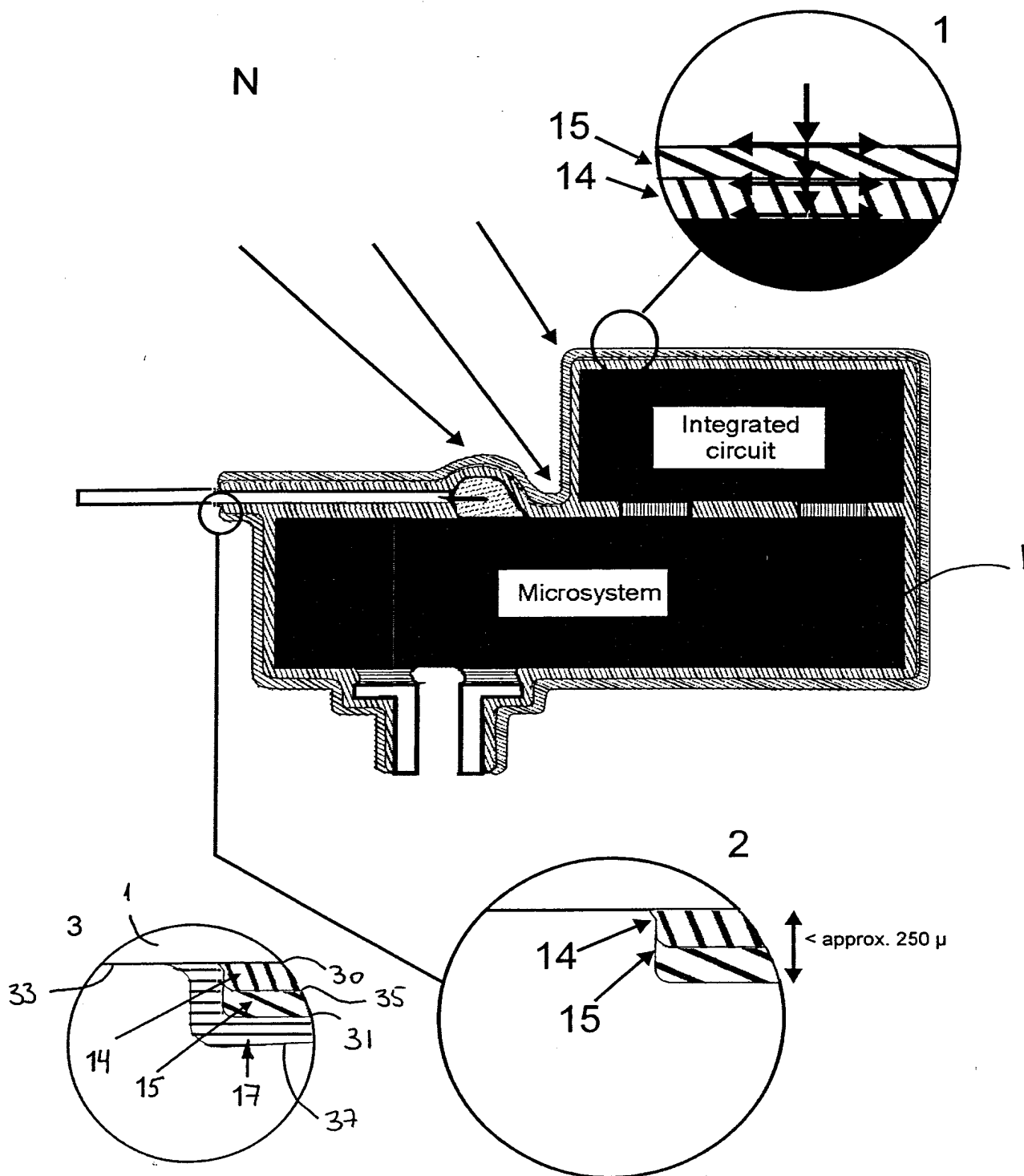


Fig. 2



**Fig. 3**

4/10

**Fig. 4**



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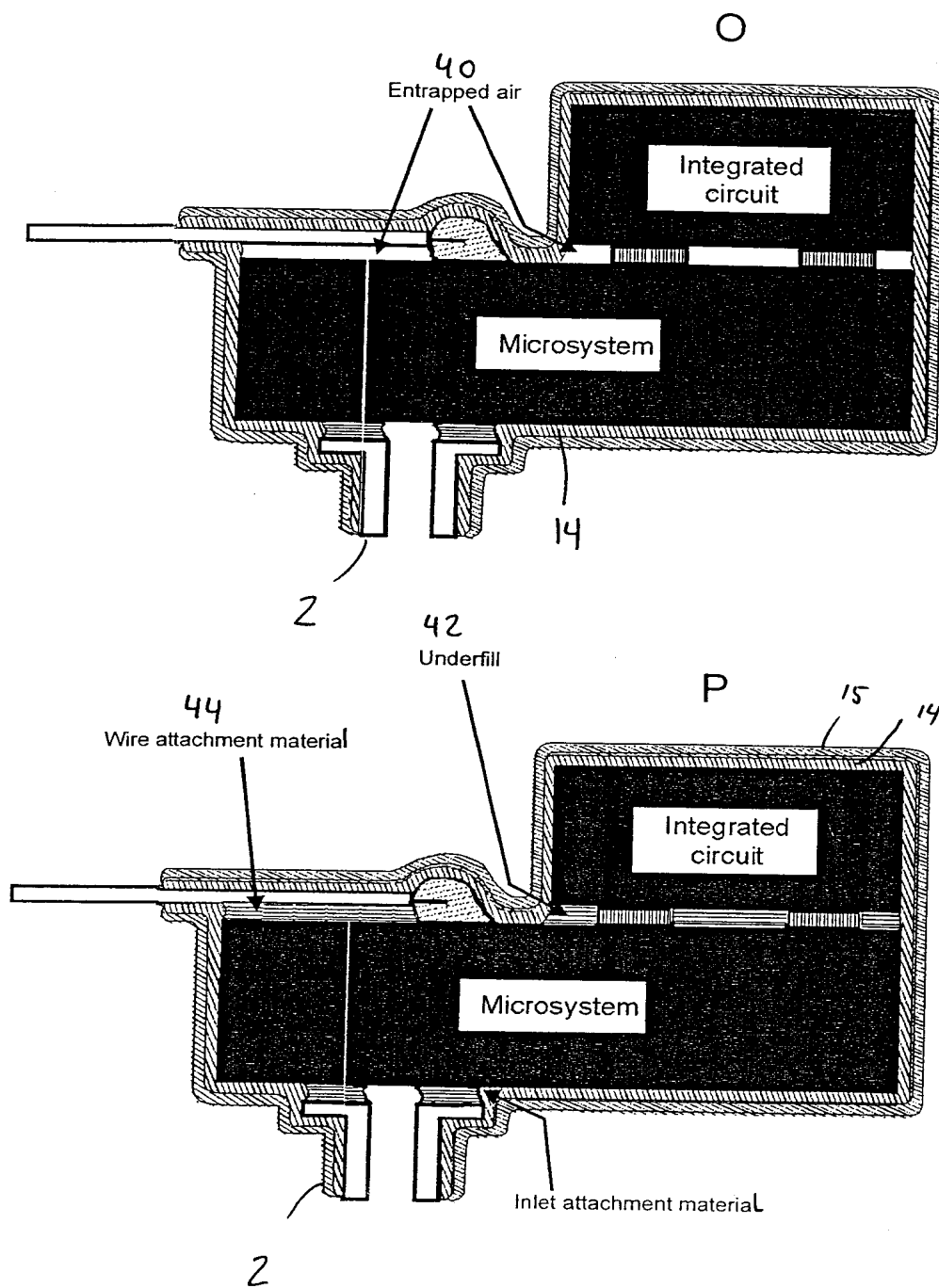


Fig. 5

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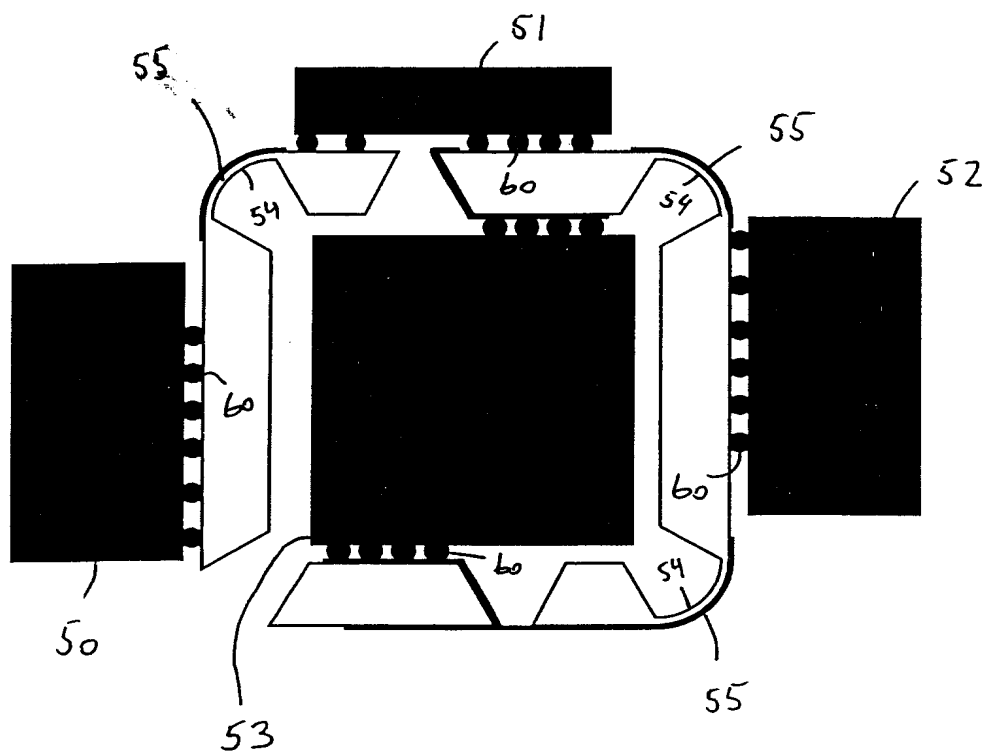


Fig. 6

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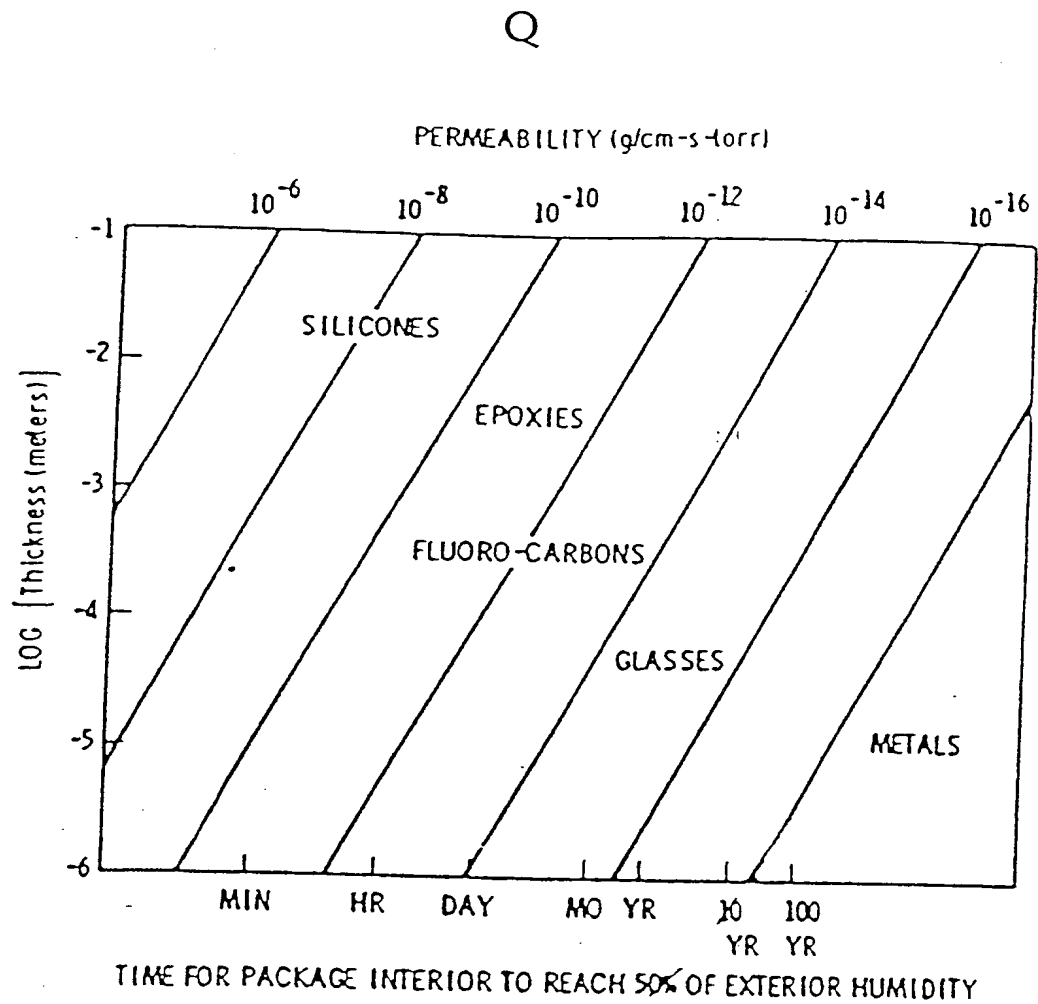


Fig. 7

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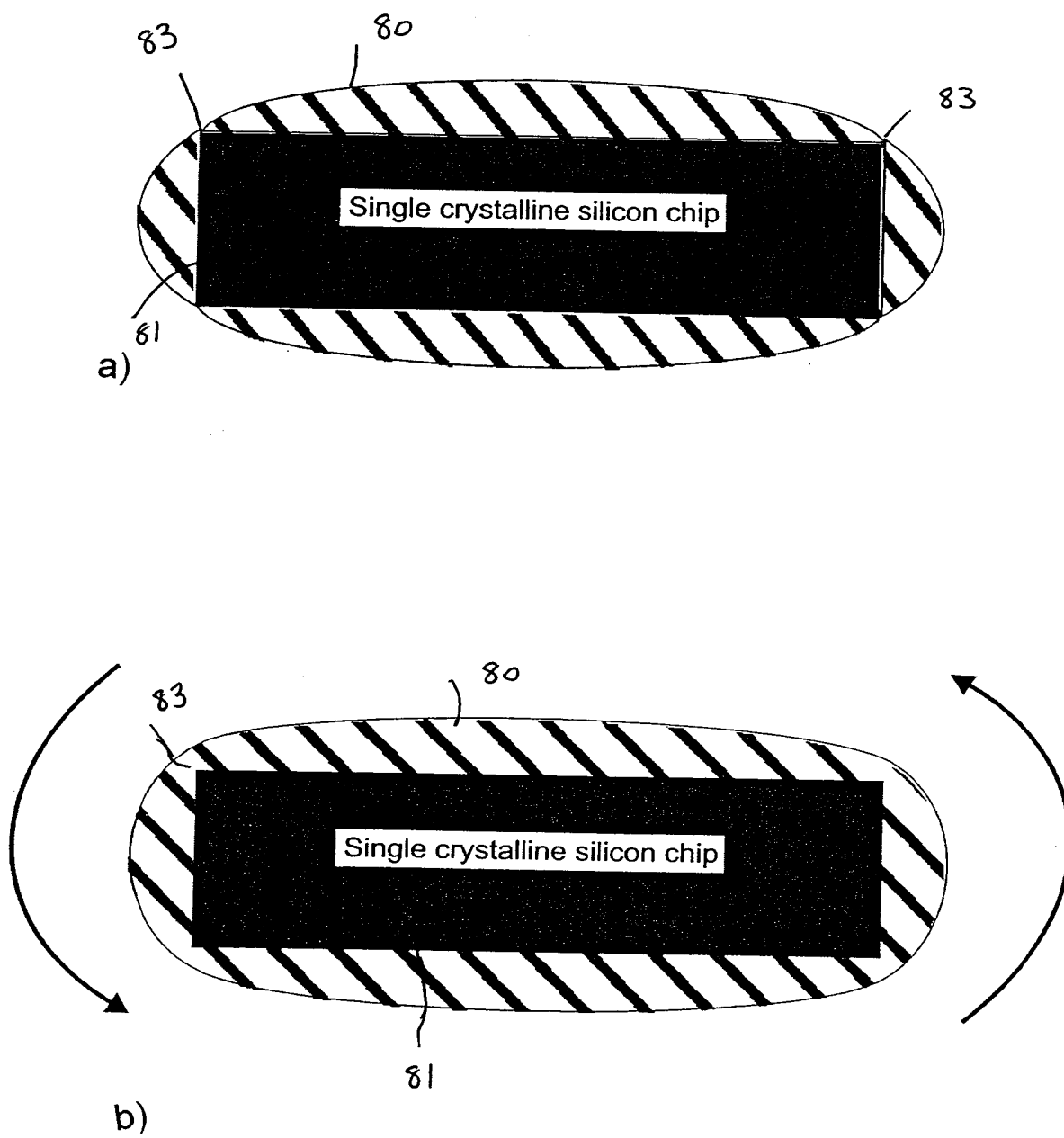


Fig. 8

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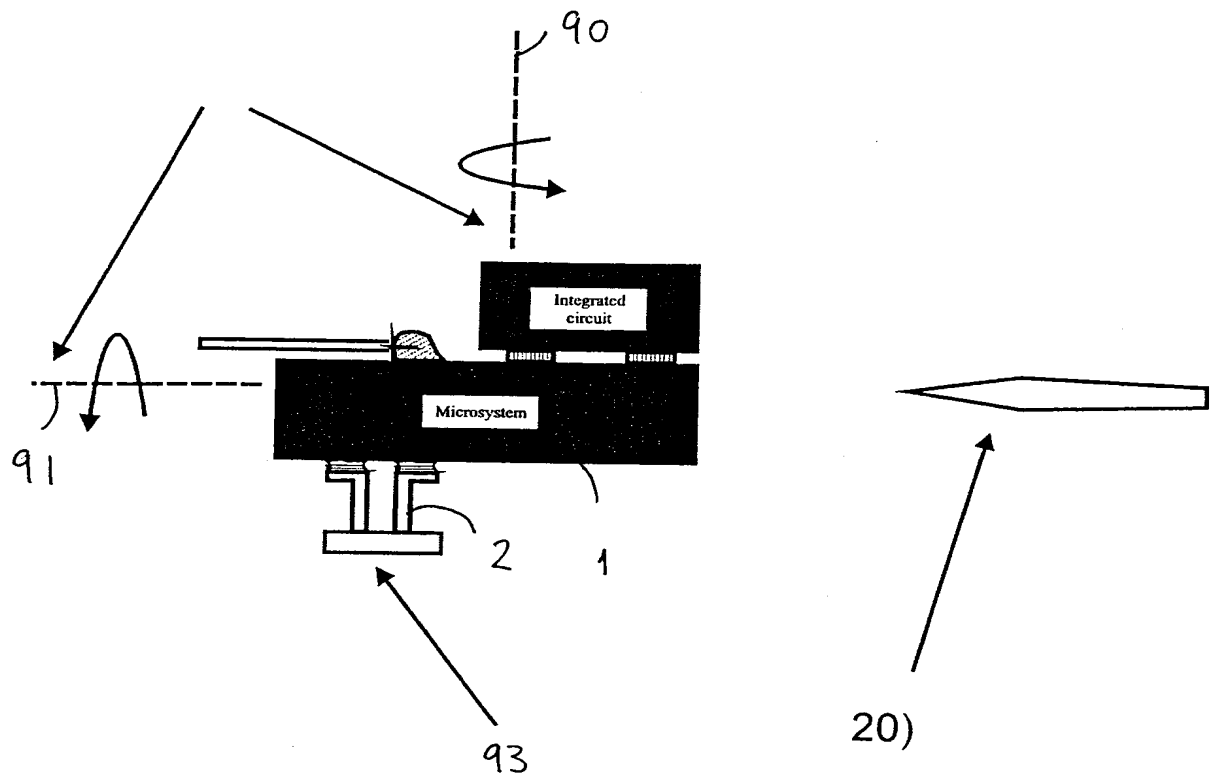
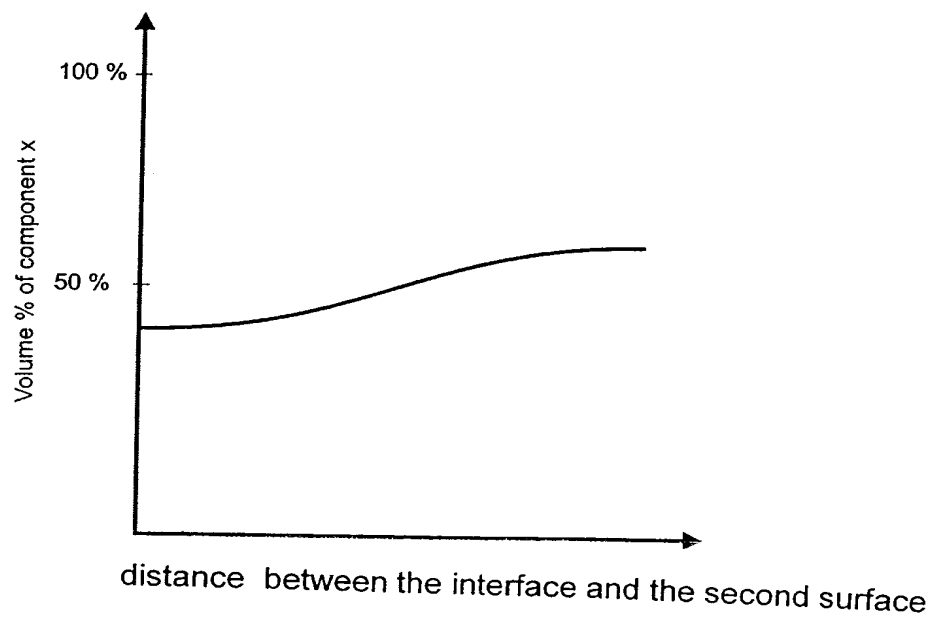


Fig. 9

**10/10****Fig. 10**

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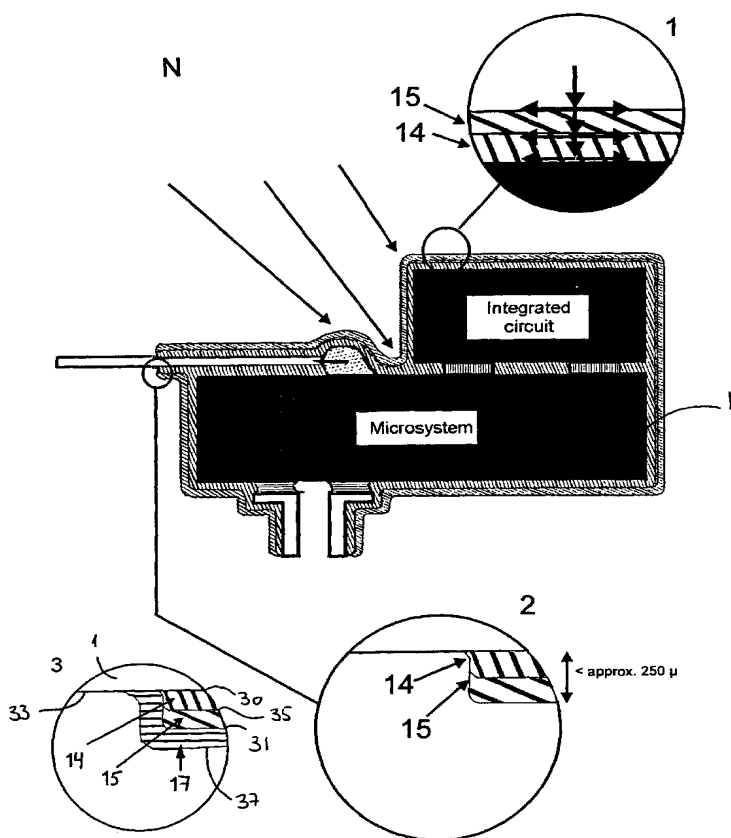
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[Continued on next page]

(54) Title: ENCAPSULATION FOR A THREE-DIMENSIONAL MICROSYSTEM



(57) Abstract: The present invention relates to an encapsulation for a microsystem. The microsystems may comprise a sensor, transducer, actuator, MEMS or other three-dimensional microsystems. The encapsulation may serve as a protection against environments such as, chemical attack, physical attack, fluid penetration and Electro Magnetic Interference. The choice of materials of the encapsulation depends on the object of encapsulation. The actual encapsulation may be applied by providing a first layer of a first material onto at least part of an outer surface of the microsystem, providing a second layer of a second material onto the first layer.

WO 01/26136 A3



MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SK (utility model), SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

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## INTERNATIONAL SEARCH REPORT

International Application No

PCT/DK 00/00559

A. CLASSIFICATION OF SUBJECT MATTER  
 IPC 7 B81B7/00 G01L9/00

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 B81B G01L H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 736 757 A (MOTOROLA INC) 9 October 1996 (1996-10-09)  the whole document	1-4, 7-16,30, 31
A	--- PATENT ABSTRACTS OF JAPAN vol. 1995, no. 05, 30 June 1995 (1995-06-30) & JP 07 035628 A (KYOWA ELECTRON INSTR CO LTD), 7 February 1995 (1995-02-07) abstract	32
A	--- US 4 163 072 A (SOOS NICHOLAS A) 31 July 1979 (1979-07-31) the whole document  --- -/-	1,4,7,8, 12,13,15

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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"&" document member of the same patent family

Date of the actual completion of the international search

8 January 2001

Date of mailing of the international search report

18.05.01

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## INTERNATIONAL SEARCH REPORT

International Application No

PCT/DK 00/00559

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	PATENT ABSTRACTS OF JAPAN vol. 009, no. 302 (E-362), 29 November 1985 (1985-11-29) & JP 60 140739 A (HITACHI SEISAKUSHO KK), 25 July 1985 (1985-07-25) abstract ---	9
A	WO 98 54556 A (OSAJDA MARC ;PERRAUD ERIC (FR); MOTOROLA SEMICONDUCTEURS (FR)) 3 December 1998 (1998-12-03) figure 2 ---	1-16
A	DE 40 40 822 A (BOSCH GMBH ROBERT) 2 July 1992 (1992-07-02) the whole document ---	22,23, 26,27
A	PATENT ABSTRACTS OF JAPAN vol. 010, no. 313 (E-448), 24 October 1986 (1986-10-24) & JP 61 125022 A (NEC CORP), 12 June 1986 (1986-06-12) abstract; figures 1-3 -----	22,23, 26,27

# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/DK 00/00559

## Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:  
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:
3. ☐ Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

## Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-16,22,23,26,27,30-32

### Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
- ☐ No protest accompanied the payment of additional search fees.

**FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210**

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. Claims: 1-16, 22, 23, 26, 27, 30-32

Double and triple protective layer of specific thickness for microsystem and its fabrication process.

2. Claims: 17-21, 24, 25, 28, 29

Single graded protective layer for microsystem and its fabrication process.

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/DK 00/00559

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